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P. 14

NASA Technical Memorandum

NASA TM - 103594

A REDUCED GRAVITY FIBER PULLING APPARATUS

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Materials and Processes Laboratory
Science and Engineering Directorate

July 1992

(NASA-TM-103594) A REDUCED GRAVITY FIBER PULLING APPARATUS (NASA) 14 p

N92-30971

Unclas

G3/29 0114114

National Aeronautics and
Space Administration

George C. Marshall Space Flight Center

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
July 1992

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
A Reduced Gravity Fiber Pulling Apparatus

5. FUNDING NUMBERS

6. AUTHOR(S)
D.S. Tucker

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-103594

11. SUPPLEMENTARY NOTES
Prepared by Materials and Processes Laboratory, Science and Engineering Directorate.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A reduced gravity fiber pulling apparatus (FPA) has been constructed in order to study the effects of gravity on glass fiber formation. The apparatus was specifically designed and built for use on NASA's KC-135 aircraft. Four flights have been completed to date during which E-glass fiber was successfully produced in simulated lunar gravity.

14. SUBJECT TERMS
Fiber Pulling Apparatus
Reduced Gravity
Glass Fiber

15. NUMBER OF PAGES
15

16. PRICE CODE
NTIS

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)

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Introduction

With NASA's commitment to a permanent manned presence in low earth orbit (Space Station Freedom) and eventual return to the moon, numerous studies have been undertaken in the areas of microgravity and lunar materials processing.[1,2] Continuous glass fiber processing is one such area of research interest. In low earth orbit, processing of optical and single crystal fibers may be enhanced due to the absence of gravity forces.[3] In fact, a miniaturized fiber pulling apparatus for drawing single crystal core glass fibers in low earth orbit has been developed.[4] On the lunar surface, abundant materials exist which can be used to produce structural materials. The use of lunar regolith for the production of structural materials could greatly reduce the cost for construction and long-term habitation of a lunar colony. One lunar product, fiberglass, promises ease of manufacture and wide applicability.[5] Continuous fiberglass could be utilized as reinforcement in structural composites, including pressure vessels, glass cables and woven fiber insulation.

This paper describes an apparatus which is used to study the effects of reduced gravity on continuous glass fiber formation. This apparatus has been flown on board NASA's KC-135 aircraft.

Description of Apparatus

Referring to figure 1, the fiber-pulling apparatus (FPA) consists of a furnace and temperature controller, take-up reel and winding motor, video camera, quench plate and heat exchanger. These components are enclosed in a plexiglas box. There is an inlet for dry nitrogen gas so that the relative humidity of the apparatus can be reduced during fiber drawing. A hygrometer is located on the inside rear wall of the apparatus which reads relative humidity.

The FPA is controlled by a data acquisition system. This system consists of an IBM personal computer, super VHS video recorder and electronics for the winding servo-motor and furnace (figure 2). A computer program controls the winding speed of the take-up reel and displays data pertinent to the drawing operation on the computer screen. This data includes 3-axes acceleration data acquired by an accelerometer, furnace and sample temperature, winding speed in cm/sec and time and date.

The furnace (figure 3) consists of an alumina tube wound with platinum heating wire encased in felt insulation. The furnace housing is made from aluminum. A platinum bushing with a single orifice is located within the platinum wound alumina tube. Bushings with a 2mm and 4mm diameter orifice are used. Thermocouples are placed on the bushing to measure the furnace temperature and at the orifice to measure sample temperature. Temperature is controlled by a temperature controller located on the outside front wall of the FPA. A platinum coated inconel sheet with a drilled center hole is located at the orifice. This sheet helps hold the bushing in place and reflects heat which would ordinarily be lost through the furnace bottom.

FPA Operation

Glass sample in centimeter size pieces is loaded into the platinum bushing via a circular hole located at the top of the furnace assembly. The temperature setpoint and ramp rate are programmed into the temperature controller and the furnace is then resistively heated to the desired temperature. The furnace operates on 120 VAC, 60 cycle and can pull up to 10 amperes of current. The maximum operating temperature of the furnace is 1600°C. The furnace is accessible through a door located at the top of the FPA. During heat-up the FPA can be purged with dry nitrogen gas which can be run continuously during the winding operation. The winder can be programmed for take-up speed in cm/sec as well as increments of increasing or decreasing speed in cm/sec. These increments are controlled by up/down arrows located on the computer keyboard. The maximum winding speed is 1000 cm/sec and the increments can be adjusted from tenths of a cm/sec to 100 cm/sec. Once the sample material has reached the appropriate drawing temperature and thus viscosity, a ceramic rod or large quartz fiber is used to manually draw the fiber from the bushing orifice to the take-up reel. The reel is a six inch diameter aluminum wheel with teflon tape applied to the take-up surface. A small piece of double-sided tape is placed on the teflon surface to facilitate initial fiber take-up. Once drawing has begun, fiber diameter can be controlled by varying winding speed and sample temperature. A video camera is positioned such that, during the fiber pulling operation, a continuous record of the fiber jet as it exits the bushing orifice can be made. Overlayed on this recording are the orthogonal three axes acceleration data in g's, furnace and sample temperature (°C), winding speed and increment of winding speed in cm/sec, date and time. A microphone located on the front of the data acquisition system allows voice description of the experiment to be recorded.

There are two options available to quench the fiber after it exits the furnace. One option is a brass annulus with a 1 mm diameter hole drilled in the center to allow the fiber to pass through. This annulus acts as a quench plate. A water/antifreeze mixture is circulated through the plate via a heat exchanger pump. This plate would be used if one were pulling a fiber above 1200°C. At temperatures above this a quench is required so that the fiber is cool enough to allow winding. This option is also useful if a fiber is being produced from a material which has a tendency towards recrystallization. Quenching the fiber rapidly helps prevent nucleation events which can adversely affect fiber properties. The other option involves using dry nitrogen gas to quench the fiber. In this method, a brass annulus with a 2 inch diameter hole in the center and twenty 0.1mm holes arranged around the inside perimeter, is used to direct nitrogen gas onto the fiber as it is pulled. This not only quenches the fiber but aids in the drawing process.

During a reduced gravity maneuver in the KC-135 aircraft, the acceleration due to gravity can be as low as 0.001g and as high as 2g. Thus, the FPA was constructed to withstand the loads seen during the parabolic manuevers, as well as 9g emergency crash loads. This reason plus on-board safety considerations is why the FPA housing was constructed as shown.

Results

Ground tests of the FPA were performed using E-glass° as the fiber forming material. E-glass is a silica based glass with well characterized fiber forming characteristics. The E-glass was supplied in 1 inch diameter marble form. These marbles were remelted at 1400°C for 24 hours in a platinum crucible and poured onto an aluminum block into droplets approximately 0.25 inch in diameter. The droplets were place into the FPA furnace and heated to 1175°C. Continuous fiber was pulled at varying winding speeds from 30 cm/sec to 1000 cm/sec.

E-glass was also used during KC-135 flights. The FPA has flown four flights to date with an average of forty manuevers per flight. All manuevers simulated lunar gravity (1/6g). The furnace again was heated to 1175°C which gave a sample temperature of approximately 1100°C. Fiber was continuously pulled throughout each manuever. During the 2g portion of the manuever, the fluid jet was observed to be 4mm in diameter at a constant winding speed of 30cm/sec. As g-load was decreased the fluid jet diameter was seen to decrease steadily to a minumum value of 3mm at 1/6g. This affected final fiber diameter as a function of g-load. At 1/6g the final fiber diameter was measured to be 100 micrometers, at 1g, 160 micrometers and 240 micrometers at 2g. It was found that if the winding speed was increased above 30 cm/sec the fiber would break approximately one inch below the orifice due to attenuation of the fiber jet at 1/6g. Fiber strength was not tested due to winding abrasion and the variation in fiber diameter due to variable g-loading.

°Owens-Illinois, Toledo, Ohio

Conclusions and Future Work

A fiber pulling apparatus has been constructed specifically for use on NASA's KC-135 reduced gravity aircraft. Continuous E-glass fiber has been pulled in simulated lunar gravity. At a constant winding speed and sample temperature, final fiber diameter is a strong function of g-loading.

Future flights are planned which will include simulated martian gravity (1/3g), micro-gravity (0g) as well as lunar gravity. In order to overcome the problem of fiber attenuation at low gravity, it is planned to add a device which will exert positive pressure on the molten glass. This device will be tied in with the accelerometer so that the pressure will vary with g-load providing a constant fiber-jet diameter and thus a constant final fiber diameter. In this manner winding speed and sample temperature (and thus viscosity) can be used to control fiber diameter.

Acknowledgements

The author would like to acknowledge Guy Smith of UAH for building the apparatus and to Andrew Setzer and Mike Effinger of EH34 for their help in testing.

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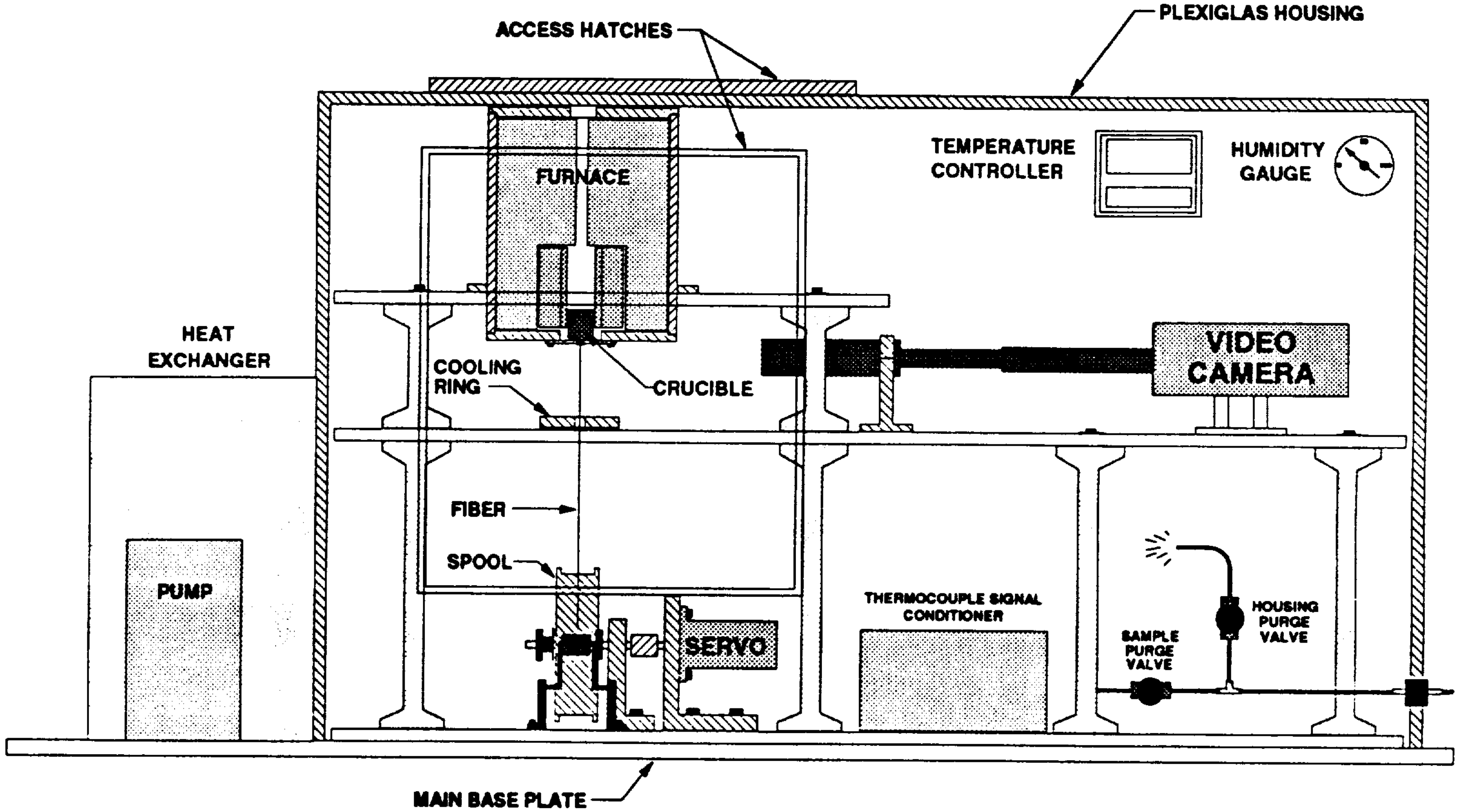
Figure 1 - Fiber Pulling Apparatus



FPA CONTROL AND DATA ACQUISITION RACK

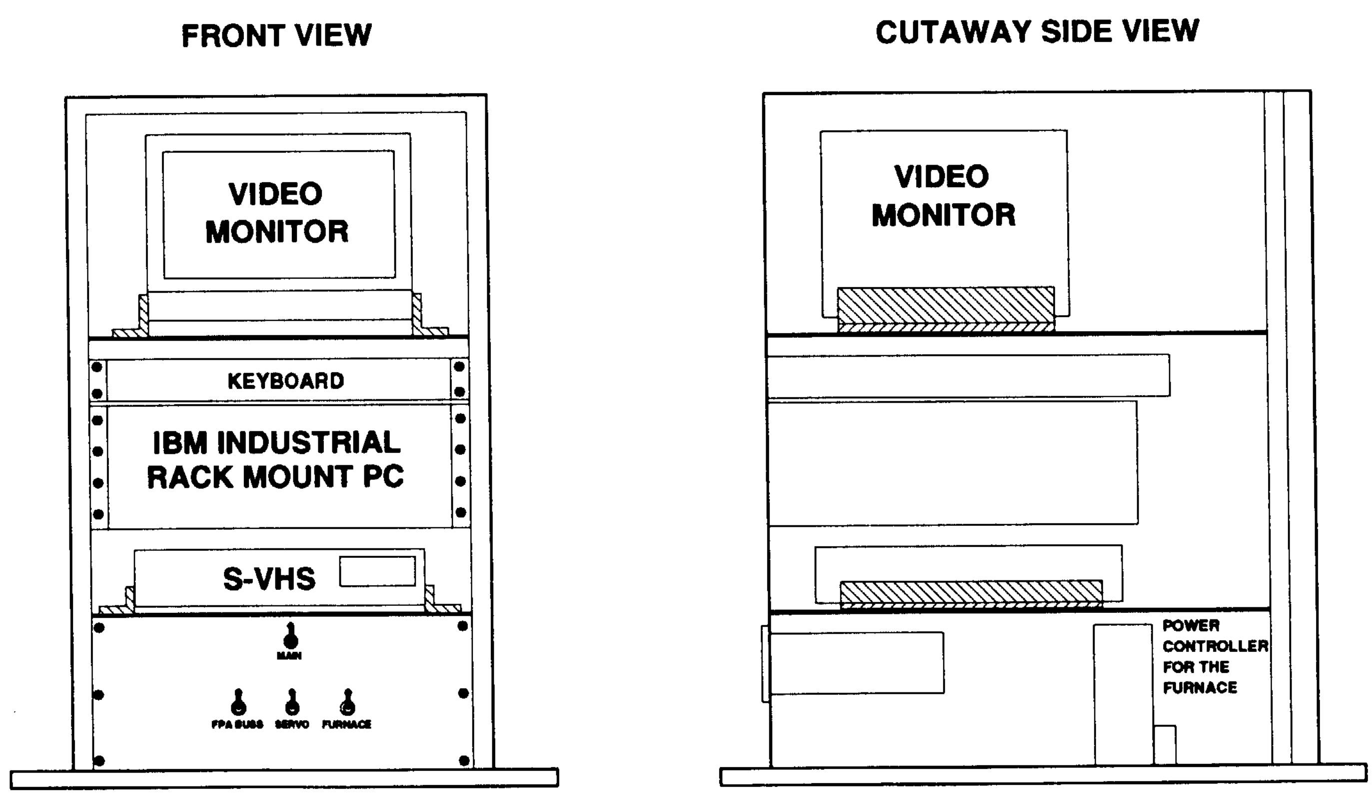


Figure 2: Data acquisition and experiment control rack for the FPA.

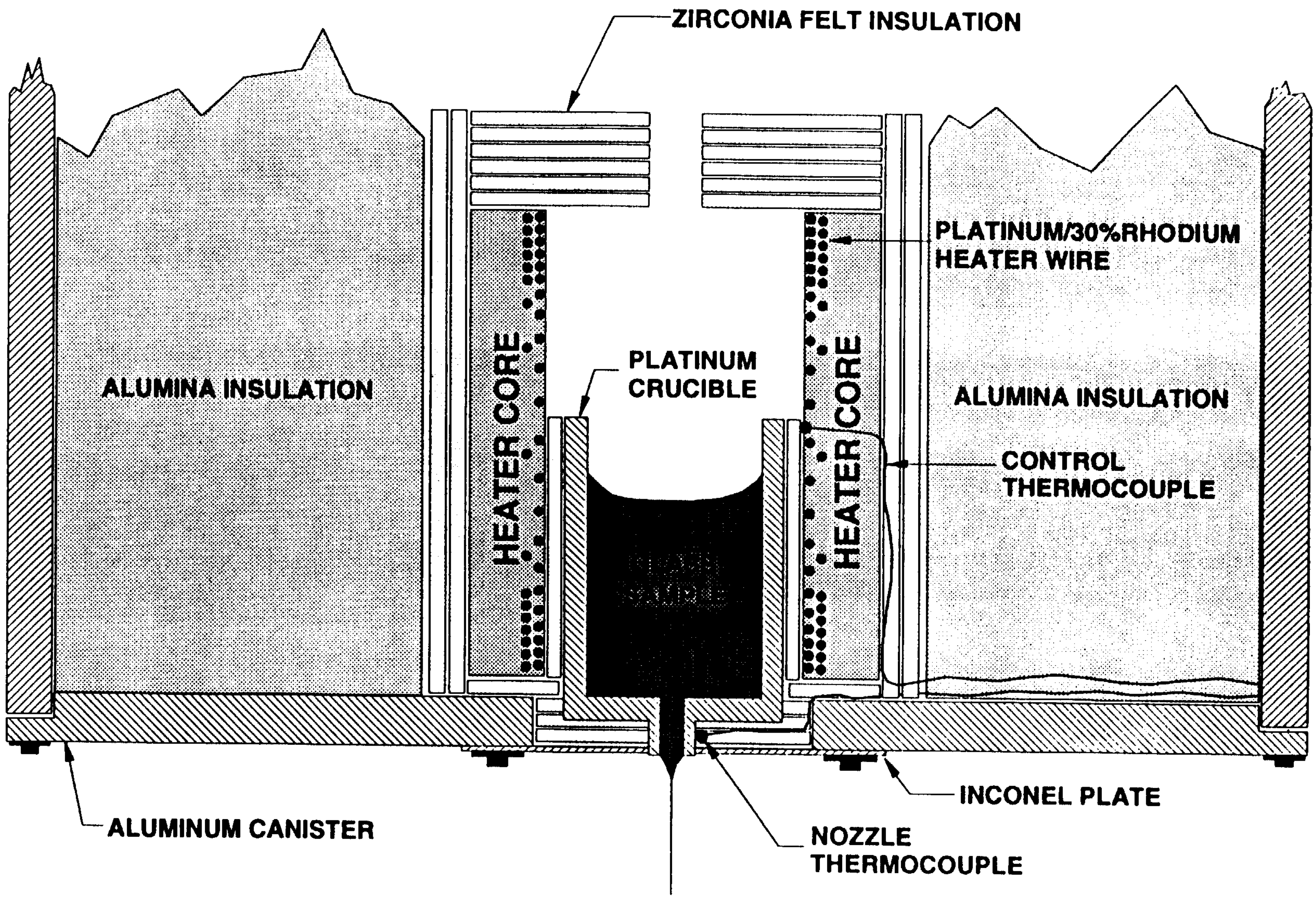


Figure 3: Furnace crossection details.

APPROVAL

A REDUCED GRAVITY FIBER PULLING APPARATUS

By Dennis Tucker

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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☆ U.S. GOVERNMENT PRINTING OFFICE 1992–631-060/60163